

# SCI TECH 2015

5 – 9 January 2015, Kissimmee, FL



## Towed Glider Air Launch System

Prepared by:

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Angie Monheim, PM Support

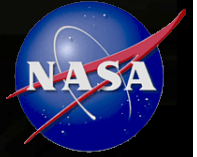
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# GOAL



Develop an affordable system that truly **enables**

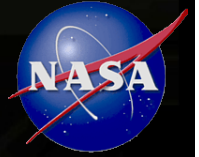
# LOD

## Launch-on-Demand Access to Space

- So far, Launch-on-Demand has not come to fruition because three key elements are not yet responsive in and of themselves
  - “On the shelf” **satellites** ready to be deployed
  - “On the shelf” **launch vehicles** ready to be deployed
  - **Flexible launch platform/range** with quick turn-around times
- These elements are getting very close to being realizable, but they need a little help to get momentum going in the right direction

An **enabling function** is needed to reach the tipping point...

# APPROACH



- Three elements must be combined to provide the enabling function

## STAGE 1: PLATFORM

Demonstrate a remotely piloted **GLIDER** carrying a small LV **TOWED** by a minimally modified business jet

## STAGE 2: LV STIMULUS

Foster integration of several small LV companies with program to demonstrate launch off the **TOWED GLIDER**

## BEHIND THE SCENES: POLICY

Work with FAA to make launch policies for small LVs using **TOWED GLIDER** as the launch platform

LV = Launch Vehicle



Ignite the small satellite launch market and make Operationally Responsive Space (ORS) and Launch On Demand a reality

# STAGE 1: PLATFORM



3 Year project to build a 100' wingspan remotely-piloted glider, modify an existing business jet for tow, and release 6000 lb LV with 100 lb satellite at 40K', 70°, M=0.8 safely & effectively.

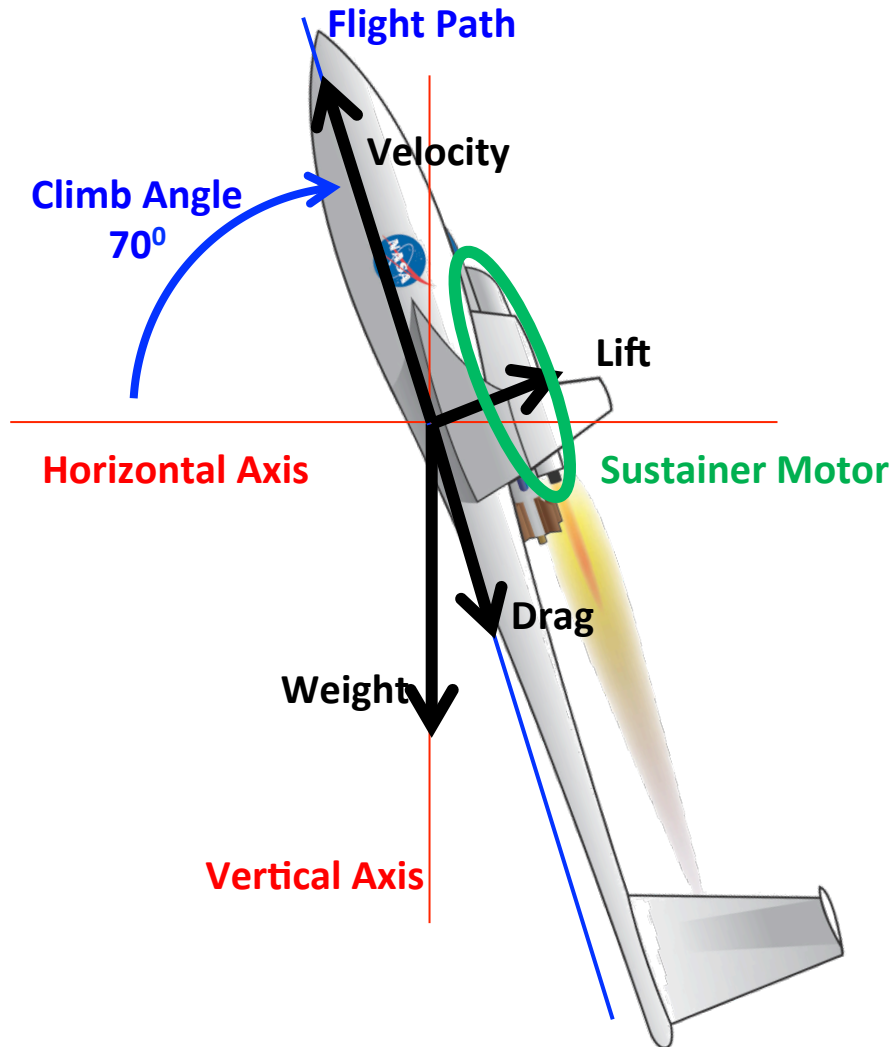
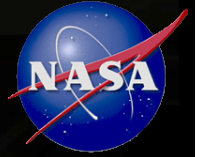
## Towed Glider Air Launch System



Simply put, the Towed Glider concept is the OPTIMIZATION of air launch



# Sustainer Motor



**Location:** Mounted on top of the glider

**Purpose:** Provides variable thrust on demand to change the Glider and LV orientation from horizontal to nearly vertical

**Features:**

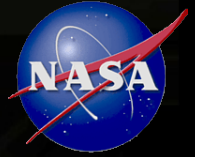
- Restartable
- Throttleable down to ~15% or less
- Controllable
- Increases Glider fly-back range

**Profile:** Start horizontal, idle sustainer motor, begin pull-up towards 70° climb, use sustainer motor variable thrust to maintain constant airspeed during climb, stabilize at 70° then release LV

The sustainer motor provides the energy to go from horizontal to nearly vertical so the LV is optimally oriented for launch

Flight demonstrating the sustainer motor concept at 1/3 scale would increase the TRL from 3 to 5 while simultaneously reducing programmatic and technical risk for the full scale program

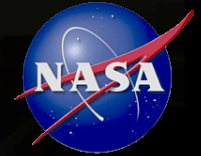
# PLATFORM: Why Towed Glider?



- High Performance: 50% plus increase in performance to orbit
  - Carry **2+ times mass to altitude** as same size direct carry conventional aircraft
  - Pull-up maneuver gives **12-15% performance increase over horizontal release**
- Low Cost
  - **No new infrastructure costs**
  - Relatively inexpensive to build a glider versus a conventional airplane
  - **Low maintenance costs** compared to a conventional airplane
  - Many existing business jets are candidate tow vehicles with minimal mods
  - Easier for small LV companies to get started without huge capital outlays
  - Commercialize-able as a separate service from LVs
- Safety & Mission Assurance
  - **Unmanned glider** eliminates human concerns for carrying LV
  - Restartable sustainer motor extends glide home distance following launch or abort
  - **Glider capable of landing with LV attached in event of mission abort**
- Flexibility
  - Glider plug-n-play center wing allows **multiple simultaneous LV build-ups**
  - **Glider and LV could fit inside C-17 tow plane** for transport to desired airfield
  - Inexpensive gliders **can be staged at any airfield, ready for immediate launch**
  - Tow plane can be existing aircraft that simply adds towed launch to duties
  - Glider concept is scalable from very small LVs

**The Towed Glider concept is the OPTIMIZATION of air launch**

# Carry Efficiency for Existing Air-Launch Platforms



Launch Platform	Gross Takeoff Weight (GTOW)	Carried Weight	Carry Efficiency, $\frac{W_{carried}}{(GTOW - W_{carried})}$
WhiteKnightTwo <sup>(2)</sup>	$70 \times 10^3$ lb	$29 \times 10^3$ lb	0.71
Stratolaunch <sup>(3)</sup>	$1.3 \times 10^6$ lb	$500 \times 10^3$ lb	0.63
B-52 Stratofortress <sup>(4)</sup>	$488 \times 10^3$ lb	$70 \times 10^3$ lb	0.17
L-1011 Stargazer	$430 \times 10^3$ lb <sup>(5)</sup>	$52 \times 10^3$ lb <sup>(6)</sup>	0.14

Key Performance Parameter			
<i>Performance Parameter</i>	<i>State of the Art</i>	<i>Threshold Value</i>	<i>Project Goal</i>
Carry Efficiency	0.71	1.5	2.0

<sup>2</sup> From FAA Draft Environmental Assessment for the Launch and Re-entry of SpaceShipTwo;  
[http://www.faa.gov/about/office\\_org/headquarters\\_offices/ast/media/20120309\\_Mojave\\_SS2\\_Draft\\_EA.pdf](http://www.faa.gov/about/office_org/headquarters_offices/ast/media/20120309_Mojave_SS2_Draft_EA.pdf).

Carried weight represents SS2 maximum launch weight; the maximum carry weight of the WK2 could not be found in the public record.

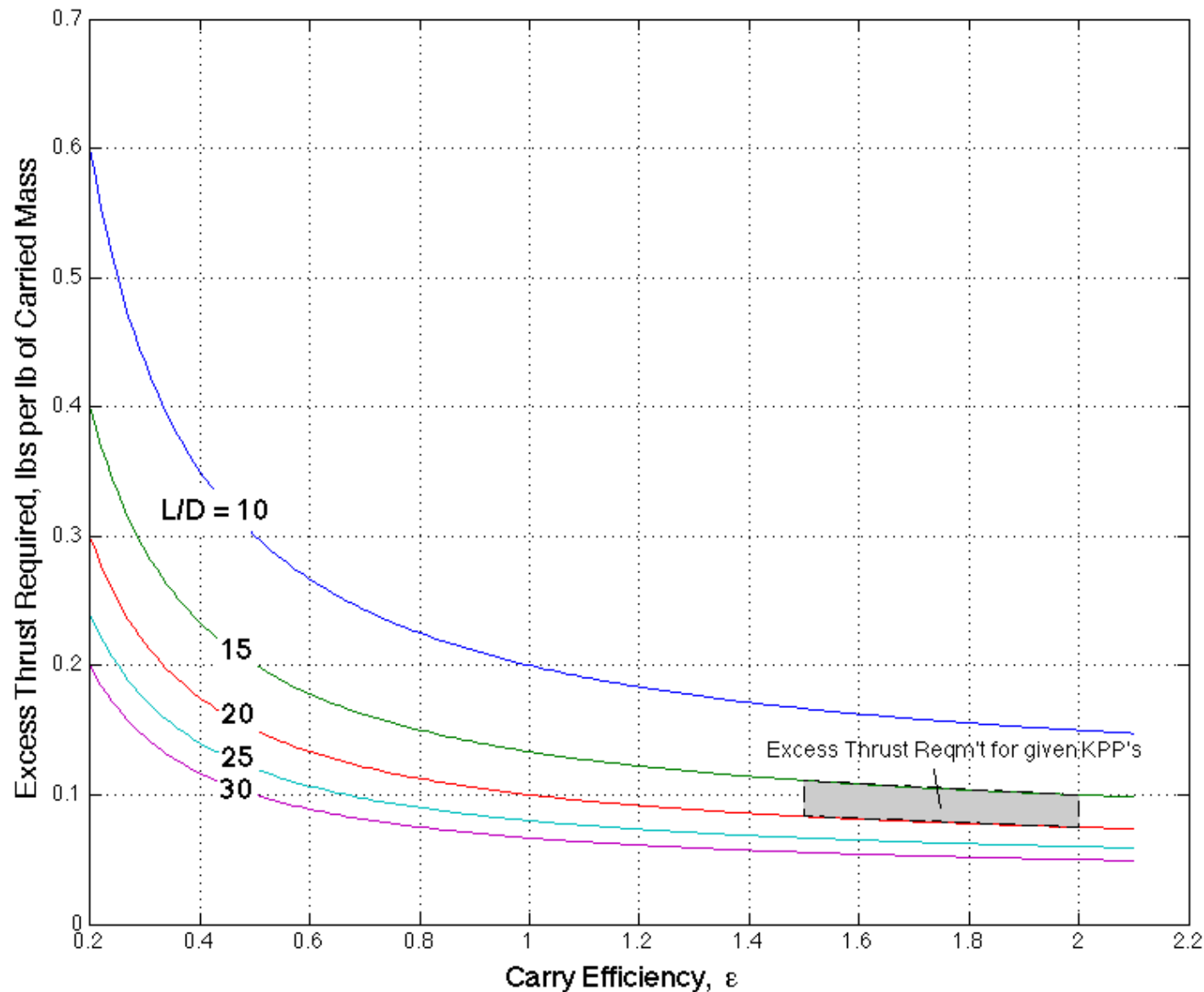
<sup>3</sup> Stratolaunch Press Kit; [http://www.stratolaunch.com/presskit/Stratolaunch\\_PressKitFull\\_May2013.pdf](http://www.stratolaunch.com/presskit/Stratolaunch_PressKitFull_May2013.pdf).

<sup>4</sup> Air Force Fact Sheet; <http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104465/b-52-stratofortress.aspx>.

<sup>5</sup> The most favorable (lightest) GTOW of the L-1011 variants; taken from [http://en.wikipedia.org/wiki/Lockheed\\_L-1011\\_TriStar](http://en.wikipedia.org/wiki/Lockheed_L-1011_TriStar)

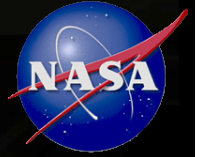
<sup>6</sup> Orbital L-1011 Fact Sheet; [http://www.orbital.com/LaunchSystems/Publications/L1011\\_factsheet.pdf](http://www.orbital.com/LaunchSystems/Publications/L1011_factsheet.pdf)

# Excess Thrust Required by Tow Airplane as a function of Carry Efficiency and Tow Glider Max L/D





# White Knight II: Direct Carry vs Towing Glider



## *Real-world example of why Towing is a better business case*

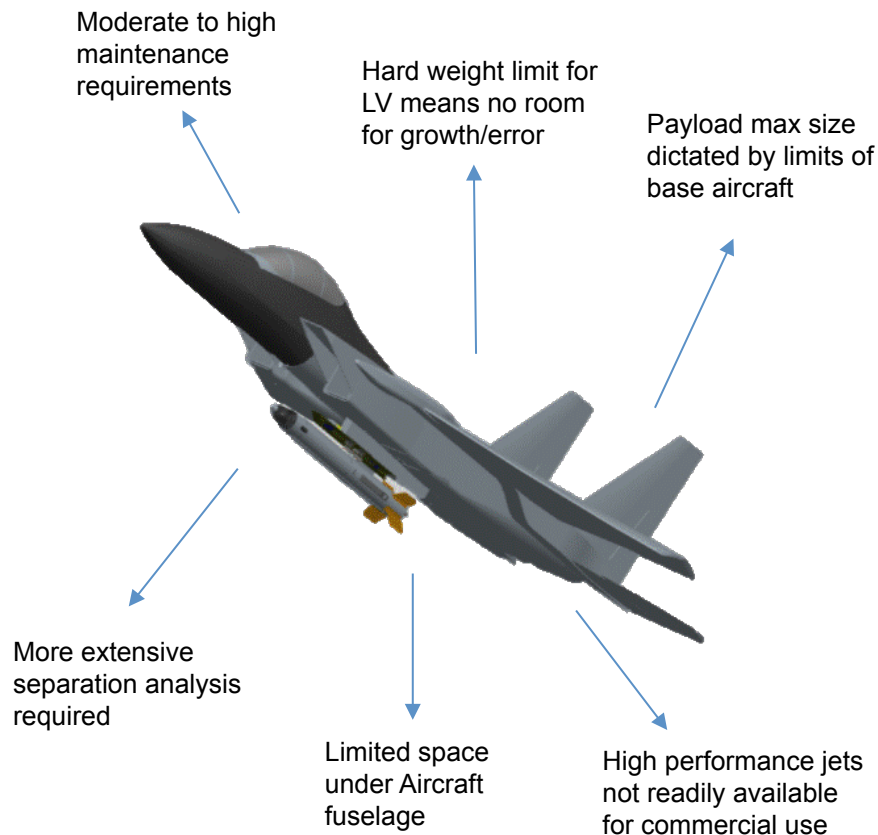
- **Question:** How much more could White Knight II (WK2) bring to altitude if Towing a Glider?
  - WK2 direct lift capability = 30,000 lbs
  - WK2 excess thrust ~ 4900 lbs (assumes 100% tow efficiency)
  - Rocket to glider weight ratio = 2:1 (rocket twice as heavy as glider)
  - Glider (with rocket attached) with 20:1 Lift to Drag ratio (L/D)
- **Math:** WK2 towing 20:1 L/D glider and rocket 2x weight of glider
  - Excess Thrust X L/D X 2/3 =  $4900 \times 20 \times \frac{2}{3} = 65,333$  lbs
  - $65,333 \text{ lbs} / 30,000 \text{ lbs} = \mathbf{2.18 \text{ times direct carry capability}}$

*Regardless of system size, using a towed glider allows us to launch 2X as much to orbit for less money than a comparably sized direct carry aircraft*

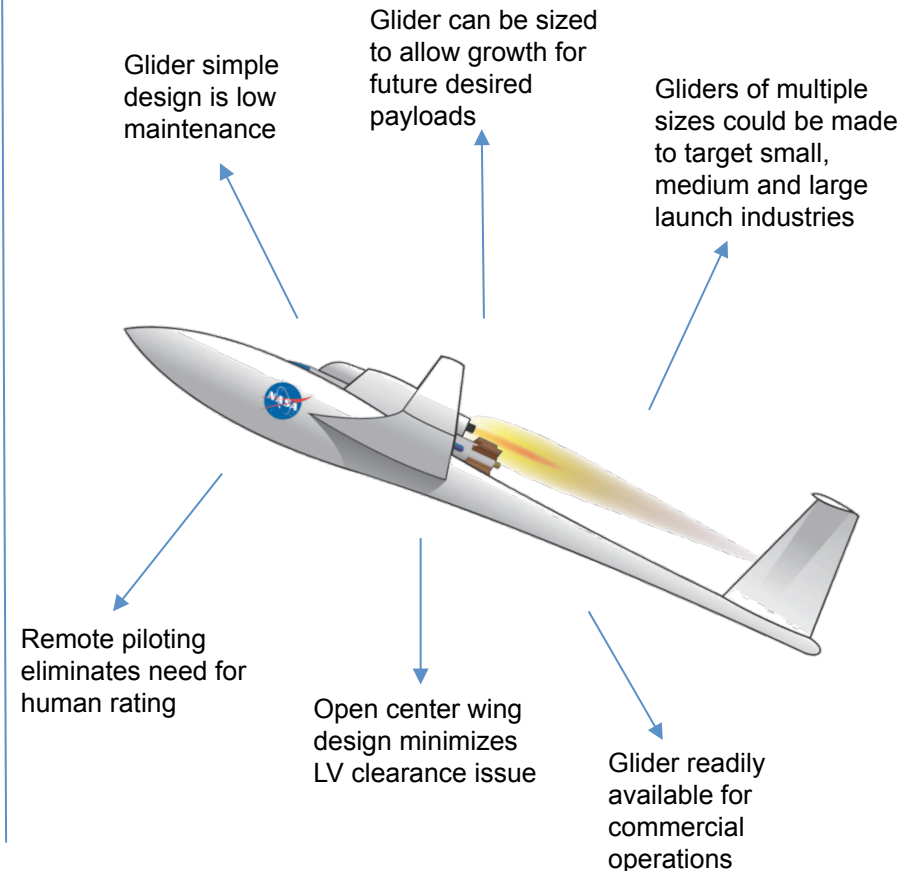
# Glider Design Creates Trade Space



## Current State of the Art: Direct Carry

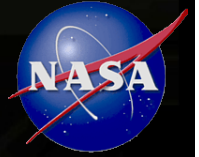


## Next Generation: Towed Glider

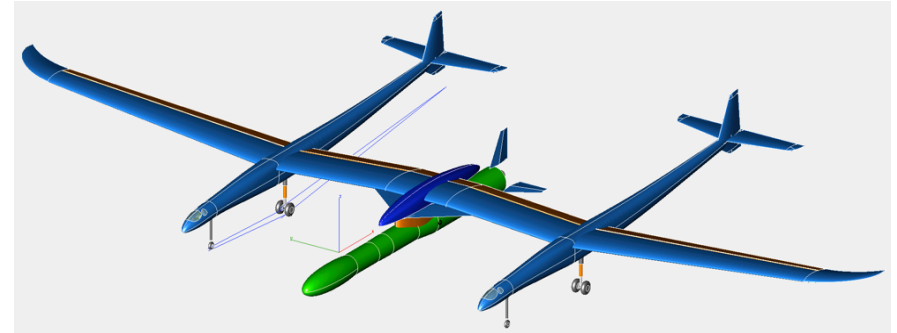


**Glider adds flexibility to ensure design success and commercializability**

# PLATFORM: SAS-ASI-Burt Rutan Study



- NASA contracted Special Aerospace Services (SAS) to study the viability of the Towed Glider Air Launch Concept
  - SAS teamed with Aerospace Services International and Rutan Designs
  - 120 Day Feasibility Study Conducted in 2012
  - Results presented in January 2013
    - Burt Rutan assessed the concept feasibility and designed a conceptual air-launch towed glider
    - Ken Lindas (SAS) analyzed the improvements in launch vehicle payload performance to orbit



Design Carry Efficiency: 1.5

- Excerpts from the SAS Study Presentation:

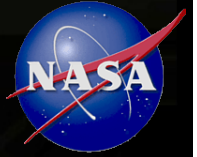
*"This world class design team was surprised in the performance enhancement relative to a Towed Carrier Aircraft leveraging an existing Launch Vehicle System."*

*"Viability should be considered for demonstration..."*

*"This is potentially game changing research with multiple Industry and USG applications."*

***The study showed the concept is do-able...next step is the Proof of Concept***

# 1/3 Scale Model Glider

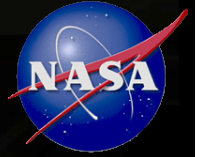


- FY13/14 Center Innovation Funds used to develop single fuselage and twin fuselage gliders for tow behind the DROID unmanned model aircraft
- Remote piloting of glider implemented using the Ground Control Station for DROID
- Whittinghill Aerospace under SBIR contract to build a small sub-orbital LV for launch demo off the twin fuselage glider
- Twin Fuselage Glider towed behind DROID to be used for 1/3 scale sustainer motor risk reduction work in FY15 (requires additional funding)





## STAGE 2: LV Stimulus

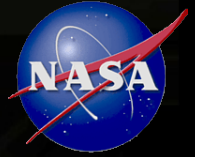


**Enables** candidate **small launch vehicle companies** to become **viable commercial launch providers** for putting small satellites into Low Earth Orbit (LEO) **on demand**.

- Stimulate Small Launch Vehicle Market
  - Development companies can enter air launch market without huge capital outlays
  - Successful launch demos could lead to future LSP contracts, as well as contracts with Industry Partners
- Stimulate Small Satellite Development Market
  - Give small satellites an affordable path to orbit without ride sharing
  - Affordable dedicated launch options will encourage new customers for small satellites

The end goal is to produce multiple viable small LV providers for the small launch market...the Glider enables them

# POLICY: Tailored for Small Launch



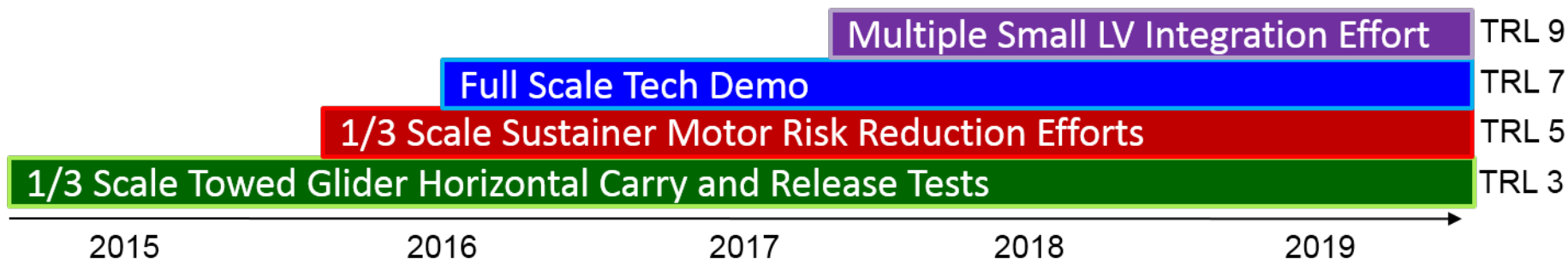
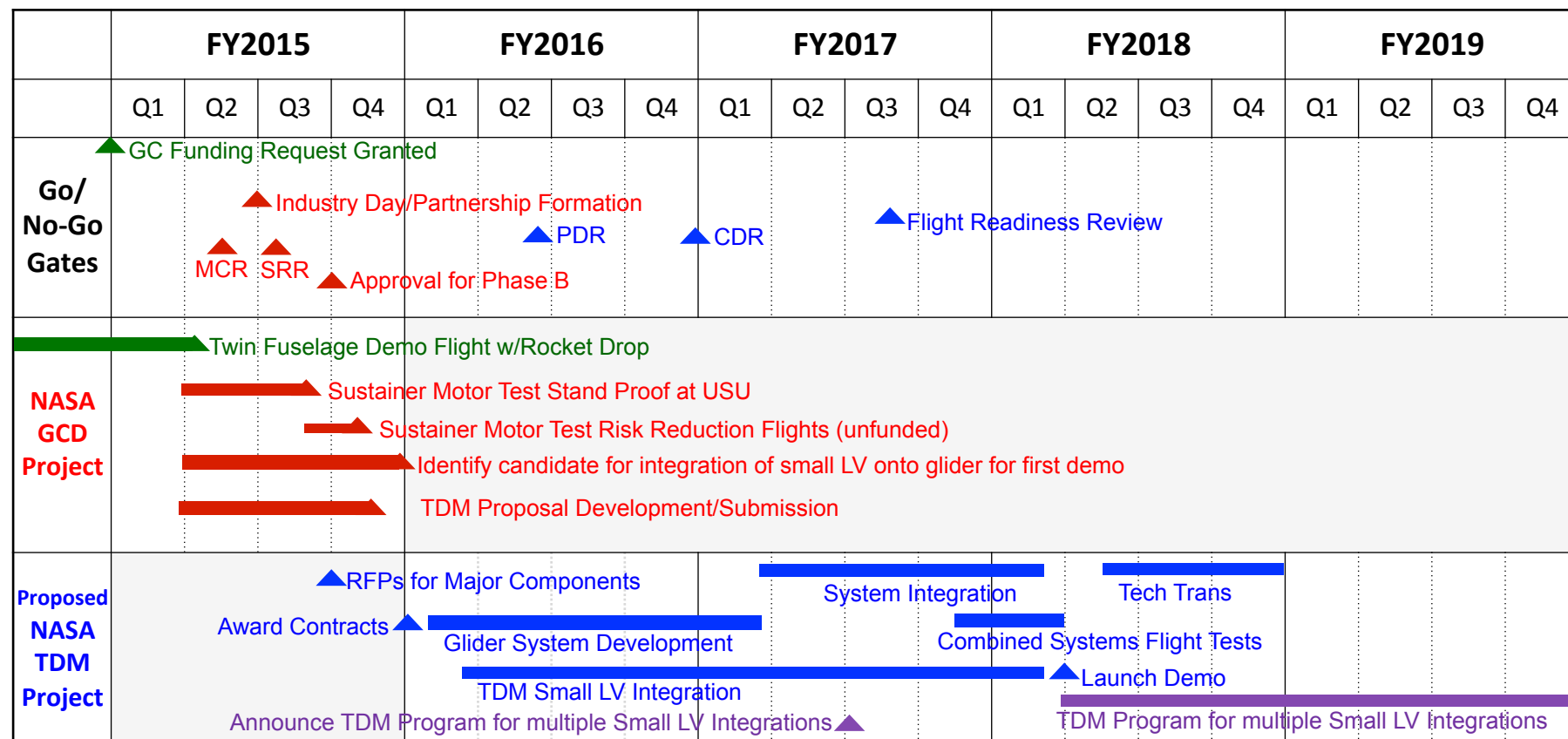
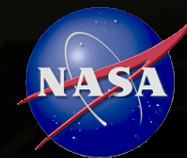
Collaborative partnership between NASA and FAA to coordinate policies and procedures which address the needs and issues associated with small launch

## POLICIES & REGULATIONS

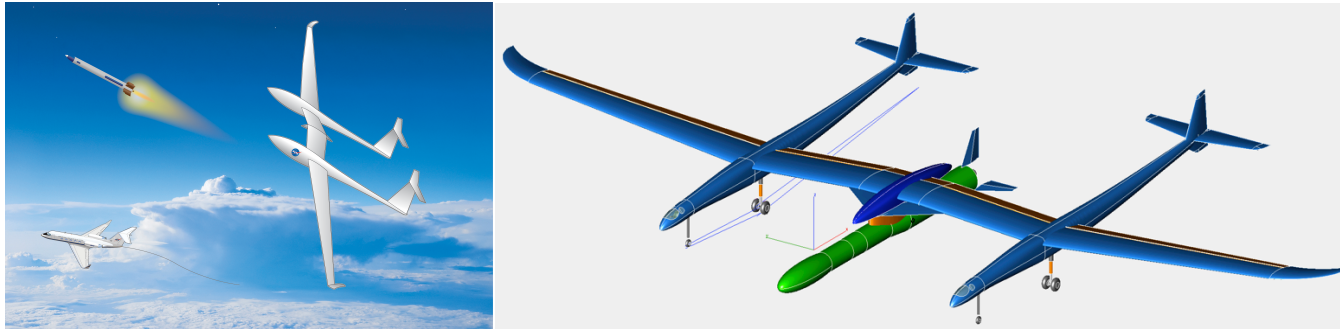
- Appropriate safety requirements for small LVs
- Certification of tow modifications to existing aircraft
- Policies and Regulations for servicing small LVs at airfields
- Paperwork and processing time that is conducive to ORS/Launch-On-Demand type CONOPS
- Coordinate streamlined conjunction assessment (CA) process and prepare for increased launch assessment traffic
- Orbital Debris Mitigation policies for the expected increase in small satellite population
- International policy concerns

The goal is to ensure NASA, government and military are prepared to accept and support the dedicated small satellite launch industry

# Schedule, Deliverables, and Key Milestones



# Summary



## Goal:

The goal is to **enable** Operationally Responsive Space.

## Approach:

PLATFORM - Remotely piloted **GLIDER** carrying a small LV **TOWED** by a minimally modified business jet

LV STIMULUS - Foster integration of several small LV companies with program to launch off **TOWED GLIDER**

POLICY - Work with FAA to make launch policies for small LVs using **TOWED GLIDER** launch platform

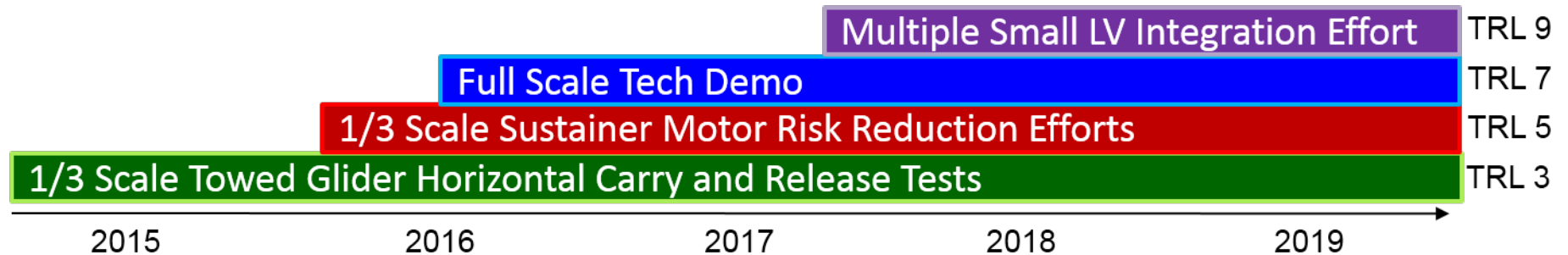
## Program:

NASA GCD Project – NASA provides funding and FTEs

Proposed NASA TDM Project – NASA provides FTEs, Partners provide \$\$, LV Candidates provide innovative new small LV technology

## Key:

**Glider acts as an enabling function to allow small launch vehicles affordable access to optimized air launch conditions they wouldn't normally be able to afford**

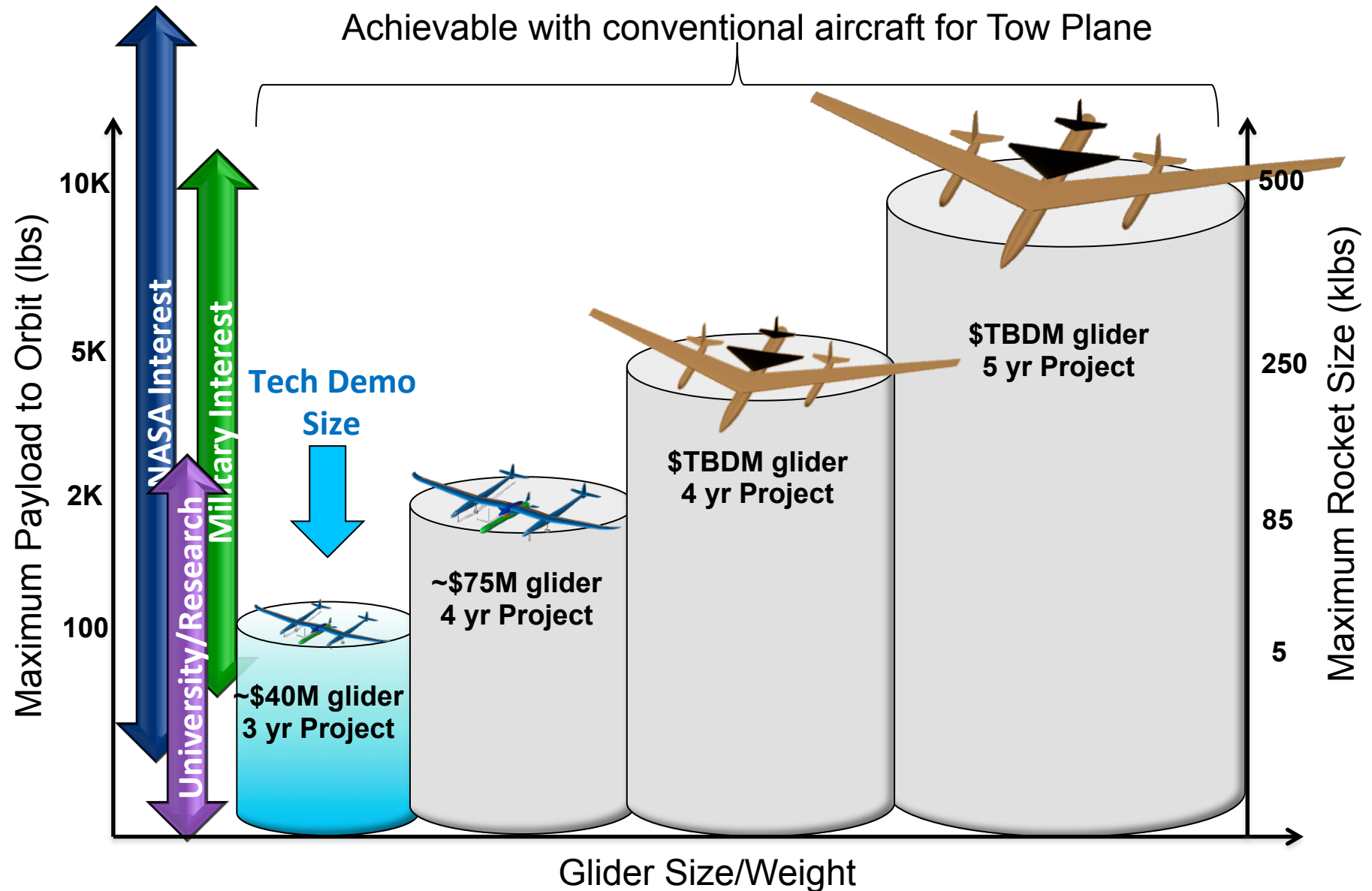






## Backup Material

# Towed Glider Technology is Scalable

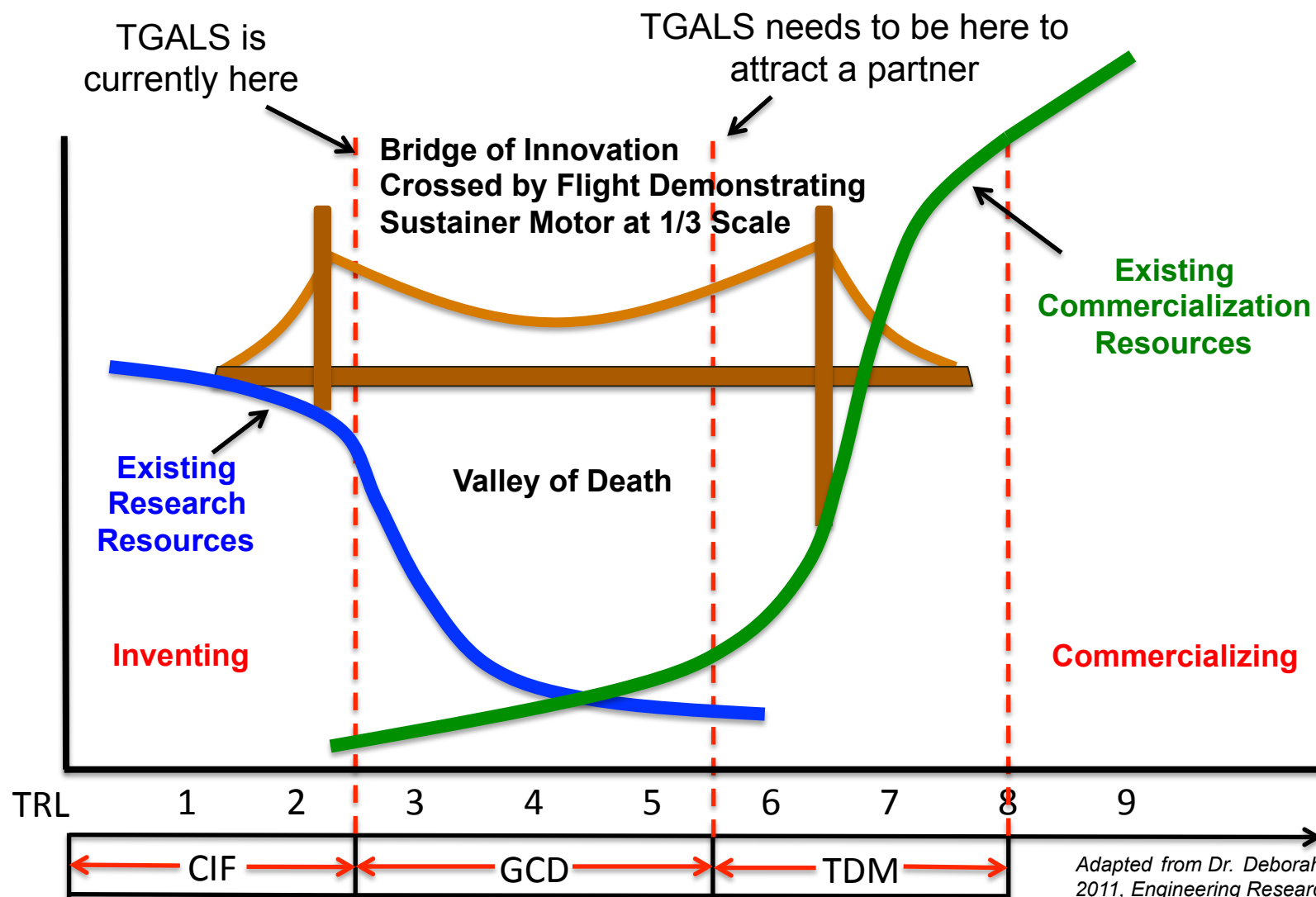


# Launch System Comparison



**Towed Glider Combines Best Attributes of Current Systems**

# “TRL Jumping” over the Valley of Death



By taking candidate low TRL concepts to flight we “jump” over the Valley of Death in 1-3 yrs



# Game Changing Potential of Towed Glider System



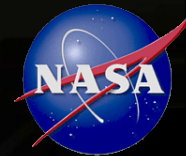
## Enable Operationally Responsive Space (ORS) and Reduce Reliance on Fixed Ranges

- Enable the dedicated small launch market to finally emerge
  - Enables ORS and Launch-on-Demand
    - COCOMs can responsively launch small satellites to meet emergent theater needs
    - Launches can originate from almost any airfield making them hard to predict
  - Enables rapid refresh of on-orbit instruments
    - Increased viability of space-based internet bringing service to remote areas
    - Allows optimized Earth Observation of emerging events on Earth
    - Bring incremental improvements in technology to orbit faster
  - Enables the possibility of cost effective dedicated small launch
- Begin to remove the reliance on fixed ground ranges
  - Help reduce future range fixed infrastructure requirements
  - Help ensure NSS launch survivability if a fixed range is rendered inoperable
  - Help optimize launch conditions for each specific orbit

*Potential to Revolutionize the Dynamics of Launch Manifesting in US*

NSS = National Security Space

# Project Snapshot: Towed Glider Air Launch



## Goal

- **Affordable System Enabling Operationally Responsive Space**

## 3 Part Program

- PLATFORM - Remotely piloted **GLIDER** carrying a small LV **TOWED** by a minimally modified business jet
- LV STIMULUS - Foster integration of several small LV companies with program to launch off **TOWED GLIDER**
- POLICY - Work with FAA to make launch policies for small LVs using **TOWED GLIDER** as the launch platform

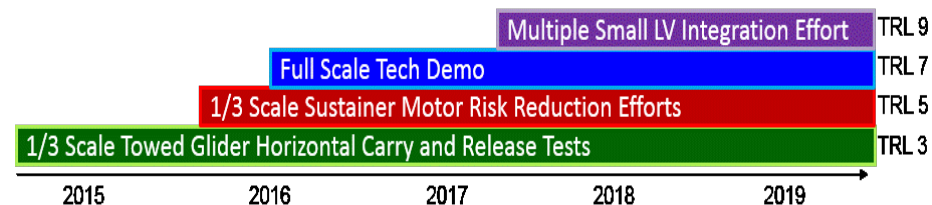
## Notional Partnership

- GCD - NASA provides funding and FTEs
- Tech Demo - NASA provides FTEs, Partners provide \$\$, LV Candidates provide innovative new small LV technology

## Why a Towed Glider?

- **High Performance: 50% plus increase in performance to orbit**
  - Carry **2+ times to alt** as same size direct carry piloted aircraft
  - Pull-up maneuver gives **12-15% increase over horizontal release**
- **Low Cost:**
  - **No new infrastructure costs**
  - **Many existing candidate tow vehicles**
  - Easier for small LV companies to get started w/o huge outlay
  - Commercialize-able as a separate service from LVs
- **Safety:**
  - **Remotely piloted** glider eliminates human concerns for LV
  - Glider capable of fly home & landing with LV attached
- **Flexibility:**
  - Glider plug-n-play center wing **allows simultaneous LV build-ups**
  - Glider and LV could fit inside C-17 tow plane for transport
  - Inexpensive gliders **can be staged at any airfield**
  - Glider concept is scalable from very small LVs

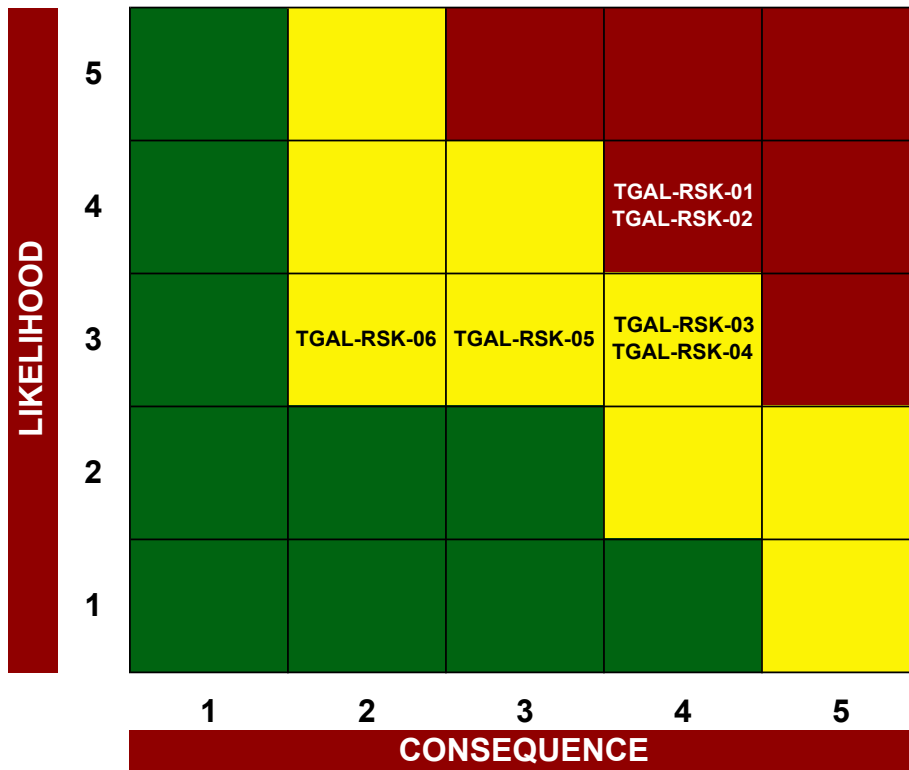
## TRL Steps



## Tech Demo Deliverables

- *Towed Glider System Development & Build-Up Flights* FY16-18
- *Small LV Integration Program* FY16-18
- *Policy Development and Coordination* FY16-18
- *Small Launch Demo off Glider and Tech Transfer* FY18

# Risk Management Matrix



Criticality	L x C Trend	Approach
High	▼ Decreasing (Improving)	M - Mitigate
Med	▲ Increasing (Worsening)	W - Watch
	► Unchanged	A - Accept
Low	▷ New Since Last Period	R - Research

## **Risk 1: Performance or operational issues with sustainer motor performance/design**

Mitigation 1: Risk-reduction ground tests in FY15 with USU sustainer motor

Mitigation 2: Risk-reduction flight tests in with 1/3 scale glider & USU sustainer motor (**currently unfunded**)

## **Risk 2: Problems with effecting new “Policy” for non-traditional launch range ops**

Mitigation: Begin investigation in FY15 of the “Core Level” requirements for performing routine launch to orbit operations outside of traditional DoD/NASA Ranges while fully meeting US and Agency requirements

## **Risk 3: Small Launch Vehicle integration delays/problems**

Mitigation: Find and fund mechanism to assist multiple small launch vehicle providers to develop candidate small LV’s for air launch from TGALS

## **Risk 4: Glider load carrying capability significantly lower than predicted/expected**

Mitigation: Risk-reduction aerodynamic performance flight tests in FY14 with 1/3-scale glider

## **Risk 5: Glider performance under tow significantly lower than predicted/expected**

Mitigation: Risk-reduction dynamic tow characterization flight tests in FY15 with 1/3-scale glider

## **Risk 6: Glider aerodynamic performance significantly lower than predicted/expected**

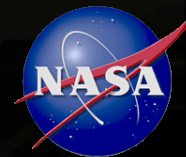
Mitigation: Risk-reduction aerodynamic performance flight tests in FY14 with 1/3-scale glider

# Socialization



Name	Position	Date
Robert Lightfoot Jr. & Lesa Roe	NASA Associate Administrator & Deputy Associate Administrator	11/25/14
Tom King	SORDAC Space – Special Operations Command	11/5/14
Dr. James Reuther & STMD DPMC	Deputy AA for Programs, Space Technology Mission Directorate	9/4/14
Dr. John Grunsfeld	Associate Administrator for the Science Mission Directorate	7/31/14
Michael Lopez-Alegria	President of the Commercial Spaceflight Federation	7/31/14
Dr. George Nield	Associate Administrator for FAA Commercial Space Transportation	7/31/14
Frank DiBello	President and Chief Executive Officer of Space Florida	7/29/14
Jay Dryer and Barbara Esker	Director and Deputy Director of the Fundamental Aeronautics Program, ARMD	6/25/14
Dr. Ellen Stofan	NASA Chief Scientist	6/23/14
Dr. James Reuther	Deputy AA for Programs, Space Technology Mission Directorate	6/20/14
DoD Joint Space Team	Executive forum advising DoD on Space issues	6/19/14
Dr. Alexander MacDonald	Assistant to David Miller, NASA Chief Technologist	6/4/14
Eric Poole	KSC Launch Services Program System Integration Engineer	6/2/14
Charles Bolden & Dr. David Miller	NASA Administrator & NASA Chief Technologist	5/13/14
Stuart Witt	Chief Executive Officer, Mojave Air and Space Port	4/17/14
Robert Lightfoot, Jr.	NASA Associate Administrator	4/15/14
Dr. Michael Freilich	Director, Science Mission Directorate, Earth Science Division	1/24/14
Steve Isakowitz	President, Virgin Galactic	10/23/13
James Wood	KSC Launch Services Program Chief Engineer	9/12/13

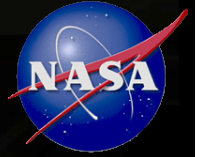
# Socialization (cont.)



Name	Position	Date
Dr. Mike Ryschkewitsch	NASA Chief Engineer (at the time)	5/21/13
Dr. Walker, Dr. Tousley, Pam Melroy	DARPA Deputy Director and DARPA Tactical Technology Office	4/29/13
Dr. Antonio Elias	Executive Vice President and Chief Technical Officer, Orbital Sciences Corp.	2/26/13
Doug Shane	President, Scaled Composites (at the time)	1/4/12



# Endorsements



April 11, 2014

Gerald D. Budd, Project Manager  
Advanced Planning and Partnerships Office, Code Z  
Neil A. Armstrong Flight Research Center  
P.O. Box 273, M/S-2701  
Edwards, CA 93523-0273

Re: Towed Glider Air-Launch Concept Project

Dear Mr. Budd,

Space Florida is pleased to express a genuine interest in facilitating the development of the Towed Glider dedicated cubesat launcher concept. We have long believed the small sat market to be as exciting a business opportunity as anything associated with technology. That future is exciting and our job is to assure that future happens here in Florida.

A partnership between Armstrong Flight Research Center and the Kennedy Space Center (KSC), as a part of the Game Changing Division of NASA's Space Technology Mission Directorate, this technology's development is encouraging. That it would then be handed off to industry to operate is what makes it so intriguing. It is the business opportunity for Florida which so aligns with our charter and our mission.

Space Florida is prepared to sponsor the development of an independent business case for the Towed Glider as a commercially-operated, dedicated cubesat launcher based at Shuttle Landing Facility (SLF). This modest investment will then be used to attract interested industry partners. Additionally, with the existing workforce, resources and facilities already maturing here on the Space Coast to support cubesat development, processing, integration, as well as the potential to process the downlinked data, this concept clearly supports the future we are trying to create here in Florida.

Also, Space Florida can readily facilitate 1) the development of a NASA-funded lease for required shop and office space at SLF for the developmental project; 2) participate in Range coordination for the developmental project; and 3) to participate in securing an industry partner.

Finally, the potential pace of work at the SLF, the further evolution of the cubesat processing and launch capability, as well as the opportunities to engage local university students in this new industry, represent exactly what it is Space Florida was created to support.

We look forward to working with you in the future on this innovative concept.

Sincerely,

Frank A. DiBello  
President & CEO  
Space Florida  
sf 14-309-dk-fad

SPACE FLORIDA

505 Odyssey Way • Suite 300 • Exploration Park • FL 32953  
[www.SpaceFlorida.gov](http://www.SpaceFlorida.gov) • f: 321.730.5307 • p: 321.730.5301

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Also, Space Florida can readily facilitate 1) the development of a NASA-funded lease for required shop and office space at SLF for the developmental project; 2) participate in Range coordination for the developmental project; and 3) to participate in securing an industry partner.

# Endorsements



April 22, 2014

Gerald D. Budd, Project Manager  
Advanced Planning and Partnerships Office, Code 2  
Neil A. Armstrong Flight Research Center  
P.O. Box 273, M/S-2701  
Edwards, CA 93523-0273

Re: Towed Glider Air-Launch Concept Project

Dear Mr. Budd,

Mojave Air and Space Port (MA&SP) is pleased and excited at the opportunity to facilitate the development of the Towed Glider dedicated cubesat launcher concept. We have direct access to special use airspace, a supersonic corridor and a letter on file from FAA authorizing access to space.

MA&SP has engaged in towed aircraft activity for nearly 70 years. Multiple commercial space companies now call Mojave home and more rocket motors have been tested here in Mojave this century than any other location on earth.

MA&SP would be very pleased to further this initiative in any way possible. At least three destinations or original points will be required in North America to reach desired space inclinations. Mojave is a natural for one of these three.

We look forward to working with you in the future on this innovative concept.

Sincerely,

MOJAVE AIR AND SPACE PORT

  
Stuart C. Witt  
Chief Executive Officer

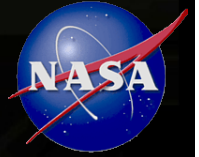
SOW/dar

Mojave Air and Space Port (MA&SP) is pleased and excited at the opportunity to facilitate the development of the Towed Glider dedicated cubesat launcher concept.

MA&SP would be very pleased to further this initiative in any way possible.

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# AFRC Historic Capabilities



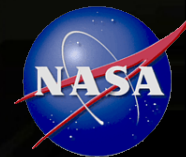
- AFRC Tow Experience
  - F-106 tow from C-141A
  - M2-F1 Lifting Body
  - **1/3 Scale Towed Glider**
- AFRC Remote Pilot Experience
  - F-15 RPRV
  - HiMAT
  - **IKHANA**
  - **DROID**
- AFRC Air Launch Experience
  - Pegasus
  - X-43
  - X-15
  - HL-10
  - M2-F2



**TGALS is an Integration of Proven Capabilities**



# TGALS CIF Activity Photos



DROID towing Twin Fuselage Glider



TGALS – Towed Glider Air Launch System



Team photo with Twin Fuselage Glider and MiniSprite Launch Vehicle during fit-check activities

# Flexible Partnering Options



## Military Partner

- Build glider system to augment existing launch capabilities
- Military sizes system to meet their tactical needs

## Big Commercial Partner

- Build glider system to be first to market with dedicated small launch capability
- Size glider to cater to projected near-term small launch market

## Hybrid Solutions

- Any 2 or more combine to pay for development of all major parts (glider, tow plane, LVs)

## NASA Demonstration

- Tech Demo of minimum cost proof of concept system (likely sub-scale)
  - Tech Transfer to industry to commercialize as they see fit

## Multiple Small Partners

- Each contributes part of the glider system to open small launch market
- Enjoy first to market status without huge capital outlays



# Excess Thrust Required by Tow Airplane as a function of Carry Efficiency and Tow Glider Max L/D

